

# Littlest Higgs model and associated $ZH$ production at high energy $e^+e^-$ collider

Chongxing Yue<sup>a</sup>, Shunzhi Wang<sup>b</sup>, Dongqi Yu<sup>a</sup>

<sup>a</sup> Department of Physics, Liaoning Normal University, Dalian 116029, China<sup>\*</sup>

<sup>b</sup> College of Physics and Information Engineering,

Henan Normal University, Xinxiang 453002, China

February 1, 2008

## Abstract

In the context of the littlest Higgs (LH) model, we consider the Higgs strahlung process  $e^+e^- \rightarrow ZH$ . We find that the correction effects on this process mainly come from the heavy photon  $B'$ . If we take the mixing angle parameter  $c$  in the range of 0.75 - 1, the contributions of the heavy gauge boson  $W'_3$  is larger than 6%. In most of the parameter space, the deviation of the total production cross section  $\sigma^{tot}$  from its SM value is larger than 5%, which may be detected in the future high energy  $e^+e^-$  collider (LC) experiments. The future LC experiments could test the LH model by measuring the cross section of the process  $e^+e^- \rightarrow ZH$ .

PACS number: 12.60.Cn, 14.80.Bn, 14.70.Hp

---

<sup>\*</sup>E-mail: cxyue@lnnu.edu.cn

## 1. Introduction

The standard model (SM) accommodates fermion and weak gauge boson masses by including a fundamental scalar Higgs  $H$ . However, the SM can not explain the dynamics responsible for the generation of mass. Furthermore, the scalar sector suffers from the problems of triviality and unnaturallness. Thus, the SM can only be an effective field theory below some high-energy scale. New physics should exist at energy scales around  $TeV$ . The possible new physics scenarios at the  $TeV$  scale might be supersymmetry [1], dynamical symmetry breaking [2], extra dimensions [3]. The present and future high energy collider experiments will test these scenarios and tell us which might be correct.

Recently, significant attention has been paid to the class of models of electroweak symmetry breaking, known as “little Higgs models” [4,5,6]. They provide a way to stabilize the weak scale from the radiative corrections of the SM and an alternative to traditional candidates for new physics at the  $TeV$  scale. They explain how the SM could be embedded in a theory valid beyond  $1TeV$ , which might solve the problems arising from the scalar Higgs boson in the SM. Little Higgs models employ an extended set of global and gauge symmetries in order to avoid the one-loop quadratic divergences. In little Higgs models, the Higgs boson is a pseudo-Goldstone boson which is kept light by an approximate global symmetry and free from one-loop quadratic sensitivity to the cutoff scale  $\Lambda_S$ . In general, these kinds of models predict the existence of the new heavy gauge bosons, such as  $W'^{\pm}, W'_3$  and  $B'$  in the extended gauge sector, which can cancel the quadratic divergences from the gauge interactions in the SM. These new particles may have significant contributions to the low energy observables and thus the precision measured data can give severe constraints on the free parameters of these kinds of models [7, 8, 9].

As the simplest realization of the little Higgs idea, the littlest Higgs (LH) model [5] is the smallest extension of the SM to date which stabilizes the electroweak scale and remains weakly coupled at  $TeV$  scale. The LH model consists of an  $SU(5)$  non-linear  $\sigma$  model which is broken down to  $SO(5)$  via a vacuum expectation value (VEV) of order  $f$ . The subgroup  $[SU(2) \times U(1)]^2$  of  $SU(5)$  is promoted to a local gauge symmetry which is broken at the same time to its diagonal subgroup  $SU(2) \times U(1)$ , identified as the

SM electroweak gauge group. The LH model predicts the existence of the new heavy particles, such as  $W'^{\pm}$ ,  $W'_3$  and  $B'$ , which should not be much heavier than  $1TeV$ . The characteristic signatures of the LH model at the present and future collider experiments and the production and decay of these new particles have been studied in Refs.[8, 10, 11]. In this paper, we consider the contributions of these new particles to associated ZH production at high energy linear  $e^+e^-$  collider (LC) experiments.

The next generation of LC is expected to operate at energies from  $300GeV$  up to about  $1TeV$  [12]. The Higgs strahlung process  $e^+e^- \rightarrow ZH$  is one of the dominant production mechanism of the Higgs boson in the future LC experiments. For the centre-of-mass energy  $\sqrt{s} = 350GeV$  and  $500GeV$  and an integrated luminosity of  $500fb^{-1}$ , this process ensures the observation of Higgs up to the production kinematical limit independently of its decay [13]. In this paper, we calculate the cross section of the process  $e^+e^- \rightarrow ZH$  in the LH model. Comparing the process  $e^+e^- \rightarrow ZH$  in the SM, this process in the LH model receives the additional contributions arising from the new gauge bosons  $W'_3$  and  $B'$ . We find that the new particles  $W'_3$  and  $B'$  can significant vary the production cross section of the process  $e^+e^- \rightarrow ZH$ . In most of the parameter space of the LH model, the deviation of the total production cross section from its SM value is larger than 5%. The future LC experiments may detect the correction effects and further test the LH model.

In the rest of this paper, we give our results in detail. The couplings of the new gauge bosons  $B'$  and  $W'_3$  to ordinary particles are given in Sec.2, which are related to our calculation. The contributions of these new particles to associated ZH production are calculated in Sec.3. Our conclusions are given in Sec.4.

## 2. The relative couplings of the neutral gauge bosons to ordinary particles

The LH model [5] is embedded into a non-linear  $\sigma$  model with the coset space of  $SU(5)/SO(5)$ . At the scale  $\Lambda_S \sim 4\pi f$ , the global  $SU(5)$  symmetry is broken into its subgroup  $SO(5)$  via a VEV of order  $f$ , resulting in 14 Goldstone bosons. The effective field theory of these Goldstone bosons is parameterized by a non-linear  $\sigma$  model with gauge symmetry  $[SU(2) \times U(1)]^2$ , spontaneously broken down to the SM gauge group

$SU(2) \times U(1)$ . The gauge fields  $W'^\mu$  and  $B'^\mu$  associated with the broken gauge symmetries are related with the SM gauge fields by:

$$W = sW_1 + cW_2, \quad W' = -cW_1 + sW_2, \quad (1)$$

$$B = s' B_1 + c' B_2, \quad B' = -c' B_1 + s' B_2, \quad (2)$$

with the mixing angles of

$$c = \frac{g_1}{\sqrt{g_1^2 + g_2^2}}, \quad c' = \frac{g'_1}{\sqrt{g_1'^2 + g_2'^2}}.$$

The SM gauge couplings are  $g = g_1 s = g_2 c$  and  $g' = g'_1 s' = g'_2 c'$ . In our calculation, we will take the mass scale  $f$ , the mixing angles  $c$  and  $c'$  as free parameters.

We denote the SM gauge boson mass eigenstates as  $W^\pm$ ,  $Z$  and  $A$  and the new heavy gauge boson mass eigenstates as  $W'^\pm$ ,  $W'_3$  and  $B'$ . The neutral gauge boson masses are given to leading order by[8]:

$$M_A^2 = 0, \quad M_{B'}^2 = (M_Z^{SM})^2 S_W^2 \left( \frac{f^2}{5s'^2 c'^2 \nu^2} - 1 + \frac{\chi_H C_W^2}{4s^2 c^2 S_W^2} \right), \quad (3)$$

$$M_Z^2 = (M_Z^{SM})^2 \left\{ 1 - \frac{\nu^2}{f^2} \left[ \frac{1}{6} + \frac{1}{4}(c^2 - s^2)^2 + \frac{5}{4}(c'^2 - s'^2)^2 + \frac{\chi^2}{2} \right] \right\}, \quad (4)$$

$$M_{W'_3}^2 = (M_Z^{SM})^2 C_W^2 \left( \frac{f^2}{s^2 c^2 \nu^2} - 1 - \frac{\chi_H S_W^2}{s'^2 c'^2 C_W^2} \right), \quad (5)$$

with

$$\chi = \frac{4f\nu'}{\nu^2}, \quad \chi_H = \frac{5S_W C_W}{2} \frac{s c s' c' (c^2 s'^2 + s^2 c'^2)}{5C_W^2 s'^2 c'^2 - S_W^2 s^2 c^2}.$$

Where  $\nu = 246 GeV$  is the electroweak scale,  $\nu'$  is the vacuum expectation value of the scalar  $SU(2)_L$  triplet and  $\theta_W$  is the Weinberg angle. The parameter  $\chi < 1$  parameterizes the ratio of the triplet and doublet VEV's. In the following calculation, we will take  $\chi = 0.5$ . From above equations, we can see that the mass  $M_Z^{SM}$  of the SM gauge boson  $Z$  gets a correction at order  $\frac{\nu^2}{f^2}$ . Since the final  $U(1)_{QED}$  symmetry remains intact, the mass and couplings of the photon are the same as those in the SM. For  $f < 3TeV$ , the mass of

the heavy photon  $B'$  may be lighter than  $500\text{GeV}$  [11]. In most of the parameter space of the LH model, the mass of the heavy gauge boson  $W'_3$  is in the range of  $1 \sim 3\text{TeV}$ .

The couplings of the neutral gauge bosons to the Higgs boson and charged leptons can be written as:

$$g_L^{Z\bar{l}} = \frac{e}{S_W C_W} \left\{ \left( -\frac{1}{2} + S_W^2 \right) + \frac{\nu^2}{f^2} \left[ \frac{c^2}{2} \left( c^2 - \frac{1}{2} \right) - \frac{5}{4} (2c'^2 - 1) \left( c'^2 - \frac{2}{5} \right) \right] \right\}, \quad (6)$$

$$g_R^{Z\bar{l}} = \frac{e}{S_W C_W} \left[ S_W^2 + \frac{5}{2} \frac{\nu^2}{f^2} (2c'^2 - 1) \left( c'^2 - \frac{2}{5} \right) \right], \quad (7)$$

$$g_L^{W'_3\bar{l}} = \frac{e}{2S_W} \frac{c}{s}, \quad g_R^{W'_3\bar{l}} = 0, \quad (8)$$

$$g_L^{B'\bar{l}} = \frac{e}{2C_W s' c'} \left( c'^2 - \frac{2}{5} \right), \quad g_R^{B'\bar{l}} = \frac{e}{C_W s' c'} \left( c'^2 - \frac{2}{5} \right), \quad (9)$$

$$g^{HZ_\mu Z_\nu} = \frac{ie^2 \nu g_{\mu\nu}}{2S_W^2 C_W^2} \left\{ 1 - \frac{\nu^2}{f^2} \left[ \frac{1}{3} - \frac{3}{4} \chi^2 + \frac{1}{2} (c^2 - s^2)^2 + \frac{5}{2} (c'^2 - s'^2)^2 \right] \right\}, \quad (10)$$

$$g^{HZ_\mu W'_{3\nu}} = -\frac{ie^2 \nu g_{\mu\nu}}{2S_W^2 C_W} \frac{(c^2 - s^2)}{2sc}, \quad (11)$$

$$g^{HZ_\mu B'_\nu} = -\frac{ie^2 \nu g_{\mu\nu}}{2S_W C_W^2} \frac{(c'^2 - s'^2)}{2s'c'}. \quad (12)$$

Where  $l$  respects the charged lepton  $e, \mu$  or  $\tau$ . If we ignore the final state masses, the partial decay widths of the heavy SU(2) gauge bosons  $V'$  ( $V = W_3, W^\pm$ ) can be written as [8, 10]:

$$\Gamma(V' \rightarrow f' \bar{f}') = \frac{C}{24\pi} ((g_L^{V'f'\bar{f}'} )^2 + (g_R^{V'f'\bar{f}'} )^2) M_{V'}, \quad (13)$$

$$\Gamma(V' \rightarrow VH) = \frac{g^2 \cot^2 2\theta}{192\pi} M_{V'} = \frac{\alpha \cot^2 2\theta}{48S_W^2} M_{V'}, \quad (14)$$

where  $f'$  is any of the SM quarks or leptons,  $C$  is the fermion color factor and  $C=1(3)$  for leptons (quarks).  $\theta$  is the mixing angle between  $V'$  and  $V$ . For the heavy gauge boson  $W'_3$ , the total decay width is:

$$\Gamma(W'_3 \rightarrow total) = \frac{\alpha}{192S_W^2} \left[ \frac{192c^2}{s^2} + \frac{(c^2 - s^2)^2}{s^2 c^2} \right] M_{Z'}, \quad (15)$$

where  $\alpha$  is the fine structure constant. Considering the precision data constraints, the mass  $M_{B'}$  of the heavy photon  $B'$  is not too heavy and is allowed to be in the region of a few hundred  $GeV$ [9]. For the decay channels  $B' \rightarrow t\bar{t}$  and  $B' \rightarrow ZH$ , we can not neglect the final state masses. The possible decay channels of the heavy photon  $B'$  have been discussed in Ref.[11].

### 3. The process $e^+e^- \rightarrow ZH$ in the LH model

The Higgs strahlung process  $e^+e^- \rightarrow ZH$  is one of the dominant production mechanism of the Higgs boson in the LC experiments. In the SM, the total cross section of this process at leading order is[14]:

$$\sigma^{SM} = \frac{(M_Z^{SM})^4 G_F^2 [1 - 4S_W^2 + 8S_W^4]}{48\pi} \frac{\sqrt{\lambda}(\lambda + 12\tilde{s}M_Z^2)}{D\tilde{s}^2}, \quad (16)$$

where  $\sqrt{\tilde{s}}$  is the centre-of-mass energy,  $\lambda = [\tilde{s} - (M_Z + M_H)^2][\tilde{s} - (M_Z - M_H)^2]$  and  $D = (\tilde{s} - M_Z^2)^2 + M_Z^2 \Gamma_Z^2$ .

Compared the process  $e^+e^- \rightarrow ZH$  in the SM, this process receives additional contributions from the heavy gauge bosons  $W'_3$  and  $B'$  in the LH model. Furthermore, in the LH model, the couplings of the SM gauge boson  $Z$  to electrons are corrected at the order of  $\frac{\nu^2}{f^2}$ . The interference effects between the correction terms and the tree-level SM coupling terms can also produce corrections to the production cross section of the process  $e^+e^- \rightarrow ZH$  at the order of  $\frac{\nu^2}{f^2}$ , which are of the same order as the corrections induced by  $W'_3$  exchange. Using Eq.(6) —Eq.(12), we can give the total production cross section  $\sigma^{tot}$  of this process in the LH model:

$$\begin{aligned} \sigma^{tot} &= \frac{M_Z^4 G_F^2}{48\pi s^4 s'^4 c'^4} \{ s^4 s'^4 c'^4 (1 - 2a) [(8C_W^4 - 12C_W^2 + 5) \\ &- 4(\nu^2/f^2)(C_W^2 - 0.5)c^2(c^2 - 0.5) - 20(\nu^2/f^2)(C_W^2 - 1.5)(c'^4 - 0.9c'^2 + 0.2)]/D_Z \\ &+ C_W^4 s'^4 c'^4 (c^2 - 0.5)^2/D_{W'_3} + 5S_W^4 s^4 (c'^4 - 0.9c'^2 + 0.2)/D_{B'} \\ &+ 2C_W^2 s^2 s'^4 c'^4 (1 - a)(c^2 - 0.5) \end{aligned} \quad (17)$$

$$\begin{aligned}
& \cdot [(C_W^2 - 0.5) - (\nu^2/2f^2)c^2(c^2 - 0.5) + (5\nu^2/2f^2)(c'^4 - 0.9c'^2 + 0.2)]/D_{ZW'_3} \\
& + 2S_W^2 s^4 s'^2 c'^2 (1 - a)(c'^4 - 0.9c'^2 + 0.2) \\
& \cdot [(3C_W^2 - 2.5) - (\nu^2/2f^2)c^2(c^2 - 0.5) - (15\nu^2/2f^2)(c'^4 - 0.9c'^2 + 0.2)]/D_{ZB'} \\
& + S_W^2 C_W^2 s^2 s'^2 c'^2 (c^2 - 0.5)(c'^4 - 0.9c'^2 + 0.2)/D_{W'_3 B'} \} \\
& \cdot \frac{\sqrt{\lambda}(\lambda + 12\tilde{s}(M_Z^{SM})^2)}{\tilde{s}^2}.
\end{aligned}$$

Where

$$\begin{aligned}
a &= \frac{\nu^2}{f^2} \left[ \frac{1}{3} - \frac{3}{4}\chi^2 + \frac{1}{2}(c^2 - s^2)^2 + \frac{5}{2}(c'^2 - s'^2)^2 \right] \\
D_{V_i} &= (\tilde{s} - M_{V_i}^2)^2 + M_{V_i}^2 \Gamma_{V_i}^2, \\
D_{V_i V_j} &= \frac{[(\tilde{s} - M_{V_i}^2)^2 + M_{V_i}^2 \Gamma_{V_i}^2][(\tilde{s} - M_{V_j}^2)^2 + M_{V_j}^2 \Gamma_{V_j}^2]}{2[(\tilde{s} - M_{V_i}^2)(\tilde{s} - M_{V_j}^2) + M_{V_i} M_{V_j} \Gamma_{V_i} \Gamma_{V_j}]}.
\end{aligned}$$

In above equations,  $V_i$  is  $Z, W'_3$  or  $B'$  and  $\Gamma_{V_i}$  is the total width of the gauge boson  $V_i$ .

To obtain numerical results, we take  $\alpha = \frac{1}{128.8}$ ,  $S_W^2 = 0.2315$ ,  $M_Z^{SM} = 91.18 \text{ GeV}$  and  $\Gamma_Z = 2.49 \text{ GeV}$  [15]. Normalized to the SM cross section  $\sigma^{SM}$ , the production cross section of the process  $e^+e^- \rightarrow ZH$  in the LH model is almost independent of the Higgs boson mass  $M_H$  because of the near cancellation of the  $M_H$ -dependence of the production cross section between in the SM and in the LH model. Thus, in our numerical calculation, we will assume  $\sqrt{\tilde{s}} = 500 \text{ GeV}$ ,  $M_H = 120 \text{ GeV}$  and take  $c, c'$  and  $f$  as free parameters.

The relative correction  $\frac{\sigma^{tot}}{\sigma^{SM}}$  is plotted in Fig.1 as a function of the mixing angle parameter  $c'$  for  $f = 2 \text{ TeV}$  and three values of the mixing angle parameter  $c$ . From Fig.1 we can see that the relative correction  $\frac{\sigma^{tot}}{\sigma^{SM}}$  is not sensitive to the mixing angle parameter  $c$  for  $c < 0.8$ . This means that the contributions of the new particles to the process  $e^+e^- \rightarrow ZH$  mainly come from the heavy photon  $B'$  in most of the parameter space. This is because the heavy gauge boson  $W'_3$  mass square  $M_{W'_3}^2$  is larger than that of the heavy photon  $B'$  at least by an order of magnitude[11]. When  $c = \frac{1}{\sqrt{2}}$ , the  $W'_3$  has no contributions to this process because the couplings of  $W'_3$  to the gauge boson  $B'$  and the SM Higgs  $H$  vanish. In this case, the deviation of the total cross section  $\sigma^{tot}$  from its SM value is larger than 5% in most of the parameter space. However, for  $0.8 \leq c < 1$ , the

contributions of the  $W'_3$  can not be ignored. The absolute value of the  $\frac{\sigma^{tot}-\sigma^{SM}}{\sigma^{SM}}$  is larger than 10%, which might be detected in the future LC experiments.

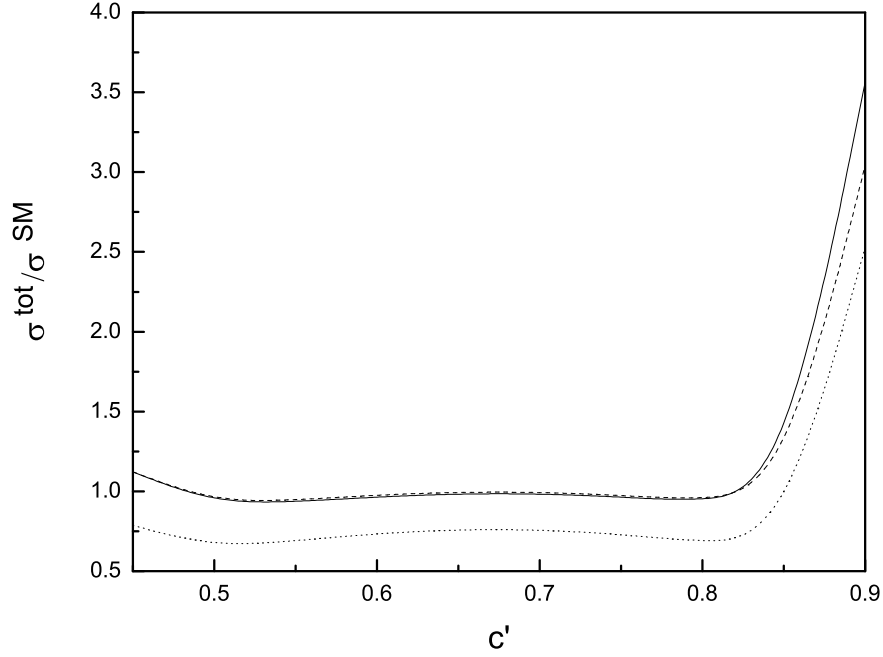


Fig.1 The relative correction  $\sigma^{tot}/\sigma^{SM}$  as a function of  $c'$  for  $f = 2TeV$  and  $c=0.1$ (solid line),  $\frac{1}{\sqrt{2}}$ (dashed line) and  $0.9$ (dotted line).

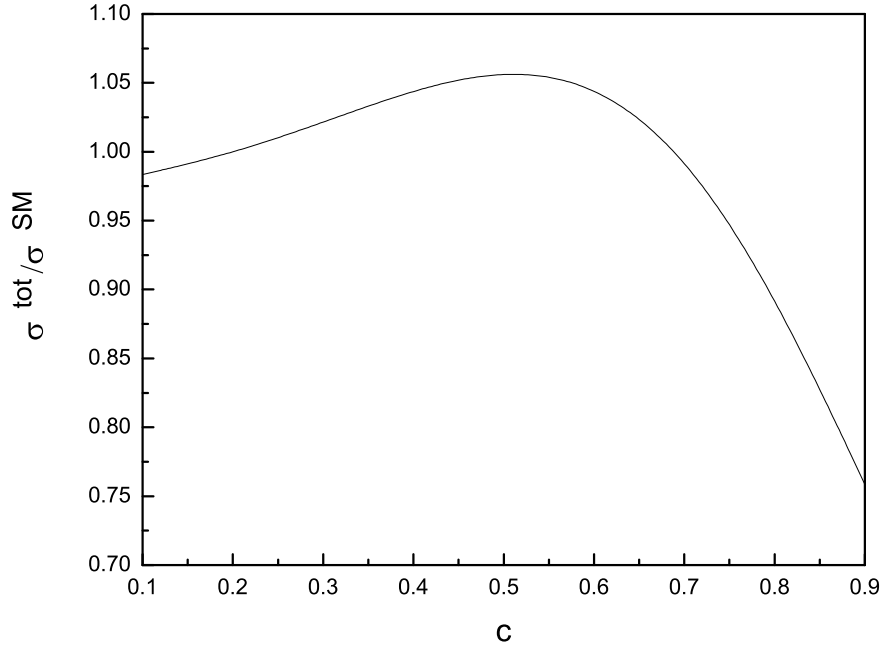


Fig.2 The relative correction  $\sigma^{tot}/\sigma^{SM}$  as a function of  $c$  for  $f = 2TeV$  and  $c' = \frac{1}{\sqrt{2}}$ .



The strongest constraints on the mass and couplings of the heavy photon  $B'$  arise from the lack of observation for the production of  $B'$ . For example, Ref.[9] has shown that for the global symmetry parameter  $f = 2TeV$ , there must be  $c' < 0.24$ , which comes from direct searches at the Tevatron. However, in the modified version of the LH model[7], only one U(1) is gauged, and there would be no heavy photon  $B'$  which corresponds to  $c' = \frac{1}{\sqrt{2}}$ . In this case, the LH model avoids constraints from Tevatron searches for heavy gauge bosons and the limits on the scale  $f$  from the electroweak data are relaxed.

To see the effects of the heavy gauge boson  $W'_3$  on the process  $e^+e^- \rightarrow ZH$ , we plot the relative correction  $\sigma^{tot}/\sigma^{SM}$  as a function of the mixing angle parameter  $c$  for  $f = 2TeV, c' = \frac{1}{\sqrt{2}}$  in Fig.2. In this case, the contributions of the heavy photon  $B'$  vanish. The absolute value of  $\sigma^{tot} - \sigma^{SM}/\sigma^{SM}$  is smaller than 5% for  $c < 0.7$ . If we assume the mixing angle parameter  $c > 0.75$ , then the gauge boson  $W'_3$  decreases the cross section of this process in the SM. The varying value of the cross section, compared to that in the SM, is larger than 6%.

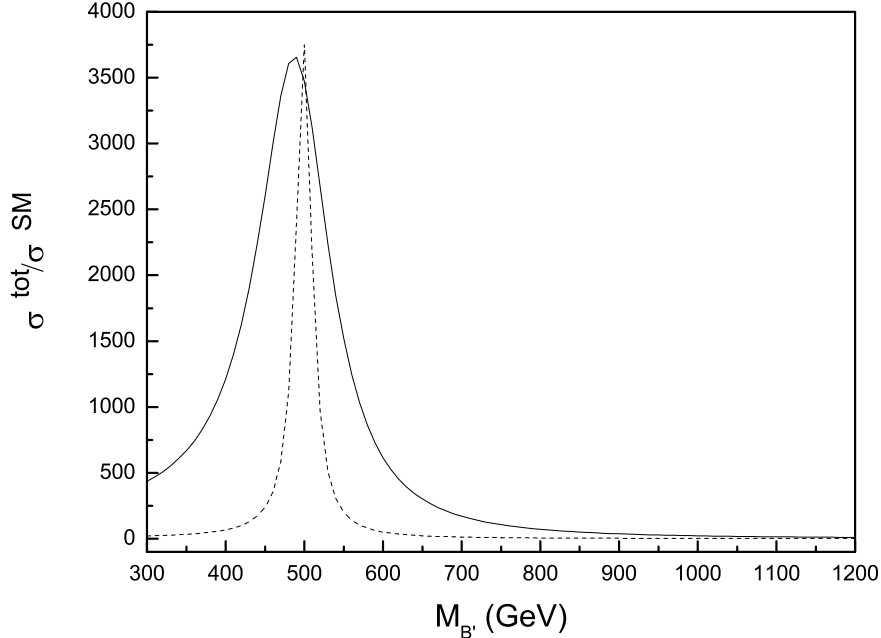


Fig.3 The relative correction  $\sigma^{tot}/\sigma^{SM}$  as a function of the heavy photon mass  $M_{B'}$  for  $c = \frac{1}{\sqrt{2}}$  and  $c' = 0.1$ (solid line),  $0.2$ (dashed line).

From Eq.(3) we can see that mass  $M_{B'}$  of the heavy photon  $B'$  mainly depends on the global symmetry breaking scale  $f$  and the mixing angle parameter  $c'$  between two U(1) gauge bosons, while is insensitive to the value of the mixing angle parameter  $c$  between two SU(2) gauge bosons. To further explain the contributions of  $B'$  to associated  $ZH$  production, we plot the relative correction  $\sigma^{tot}/\sigma^{SM}$  as a function of  $M_{B'}$  for  $c = \frac{1}{\sqrt{2}}$  and two values of the mixing angle parameter  $c' = 0.1$ (solid line),  $0.2$ (dashed line). In this case the contributions of the new particle  $W'_3$  predicted by the LH model to the process  $e^+e^- \rightarrow ZH$  is zero. For the mixing angle parameter  $c' = 0.1(0.2)$ , the peak of the total cross section  $\sigma^{tot}$  emerges when the heavy photon mass approximately equals  $480GeV(500GeV)$ . Even we take the heavy photon mass  $M_{B'} = 1200GeV$ , we have  $\sigma^{tot}/\sigma^{SM} = 2$ . Thus, in a sizable parameter region of the LH model, the heavy photon  $B'$  can produce significant new signal, which can be detected in the future LC experiments.

The cross section of the process  $e^+e^- \rightarrow ZH$  can be measured by analysing the mass spectrum of the system recoiling against the Z boson. For  $M_H = 130GeV$ , the final states are four jet  $b\bar{b}q\bar{q}$  and two jet plus two lepton  $b\bar{b}l^+l^-$ , which are coming from the Higgs boson decaying to  $b\bar{b}$ , the Z boson decaying to a  $q\bar{q}$ , and the Z boson decaying to charged leptons, respectively. From the number of signal events fitted to the di-lepton recoil mass spectrum, the production cross section of the process  $e^+e^- \rightarrow ZH$  is obtained with a statistical accuracy  $\pm 2.8\%$ , combining the  $e^+e^-$  and  $\mu^+\mu^-$  channel [12]. In most of the parameter space of the LH model, the deviation of the total production cross section from its SM value is larger than 5%. Even for  $c' = 0.2$ ,  $c = \frac{1}{\sqrt{2}}$ , and  $M'_A = 1200GeV$ , the value of the  $\sigma^{tot}/\sigma^{SM}$  can reach 2. Thus, the effects of the new particles predicted by the LH model might be observable in the future LC experiments.

#### 4. Conclusions

Little Higgs models provide a natural mechanism to cancel quadratic divergences that appear in the calculation of the Higgs mass without resorting to supersymmetry. The cancellation of divergences occurs by the alignment of vacua and the existence of several new particles. These kinds of models predict the existence of several scalars, new gauge bosons, and vector-like top quarks. The possible signatures of these models might be detected in the future high energy experiments.

The Higgs-strahlung process  $e^+e^- \rightarrow ZH$  is one of the main production process of the Higgs boson  $H$  at the LC experiments, which offers a very distinctive signature ensuring the observation of the SM Higgs boson up to the production kinematical limit independently of its decay. Using this process, we can precisely measure the Higgs mass  $M_H$  and the couplings of Higgs boson to massive gauge bosons and determine the quantum numbers of the Higgs boson. Thus, it is necessary to consider the process  $e^+e^- \rightarrow ZH$  in the context of the little Higgs models and see whether this process can be used to test these models.

In this paper, we calculate the contributions of the new gauge bosons  $W'_3, B'$  predicted by the LH model to the cross section of this process and find that the cross section can be significantly varied. In most of the parameter space, the corrections mainly come from the heavy photon  $B'$ . With reasonable values of the parameters in the LH model, the deviation of the total production cross section  $\sigma^{tot}$  from its SM value is larger than 5%. If we assume that the mixing angle parameter  $c$  is in the range of  $0.75 - 1$ , the contributions of the heavy gauge boson  $W'_3$  to the process  $e^+e^- \rightarrow ZH$  is larger than 6%. It has been shown that the modified version of the LH model[7], in which only one  $U(1)$  is gauged, can avoid constraints from Tevatron searches for heavy gauge bosons and the limits on the free parameters from the electroweak data are relaxed. Thus, it is possible that this process can be used to detect the signatures of these models.

## Acknowledgments

We are very grateful to Prof. X. Zhang for bringing little Higgs models to our attention. C.X.Yue would like to thank H. E. Logan et al. for pointing out that the effects of the

correction terms about the mass and couplings of the SM gauge boson  $Z$  on the process  $e^+e^- \rightarrow ZH$  can not be neglected. This work was supported by the National Natural Science Foundation of China (90203005).

## References

- [1] S. Dimopoulos and H. Georgi, *Nucl. Phys. B* **193**(1981)150; H. P. Nilles, *Phys. Rept.* **110**(1984)1; H. E. Haber and G. L. Kane, *Phys. Rept.* **117**(1985)75; S. P. Martin, hep-ph/9709356; P. Fayet, *Nucl. Phys. B (Proc. Suppl.)* **101**(2001)81.
- [2] For a recent review, see C. T. Hill and E. H. Simmons, *Phys. Rept.* **381**(2003)235.
- [3] I. Antoniadis, C. Munoz, M. Quiros, *Nucl. Phys. B* **397**(1999)515; N. Arkani-Hamed, S. Dimopoulos, G. R. Dvali, *Phys. Rev. D* **59**(1999)086004; L. Randall, R. Sundrum, *Phys. Rev. Lett.* **83**(1999)3370; 4690; J. L. Hewett and M. Spriopulu, *Ann. Rev. Nucl. Part. Sci.* **52**(2002)397
- [4] N. Arkani-Hamed, A. G. Cohen and H. Georgi, *Phys. Lett. B* **513**(2001)232; N. Arkani-Hamed, A. G. Cohen, T. Gregoire and J. G. Wacker, hep-ph/0202089; N. Arkani-Hamed, A. G. Cohen, E. Katz, A. E. Nelson, T. Gregoire and J. G. Wacker, hep-ph/0206020; I. Low, W. Skiba and D. Smith, *Phys. Rev. D* **66**(2002)072001; D. E. Kaplan and M. Schmaltz, hep-ph/0302049.
- [5] N. Arkani-Hamed, A. G. Cohen, E. Katz, A. E. Nelson, hep-ph/0206021; S. Chang, hep-ph/0306034.
- [6] M. Schmaltz, *Nucl. Phys. Proc. Suppl.* **117**(2003)40; J. G. Wacker, hep-ph/0208235; S. Chang and J. G. Wacker, hep-ph/0303001; W. Skiba and J. Terning, hep-ph/0305302.

- [7] C. Csaki, J. Hubisz, G. D. Kribs, P. Meade and J. Terning, *Phys. Rev. D***67**(2003)115002; **68**(2003)035009; T. Gregoire, D. R. Smith and J. G. Wacker, hep-ph/0305275.
- [8] T. Han, H. E. Logan, B. McElrath and L. T. Wang, *Phys. Rev. D***67**(2003)095004.
- [9] J. L. Hewett, F. J. Petriello and T. G. Rizzo, hep-ph/0211218
- [10] G. Burdman, M. Perelstein and A. Pierce, *Phys. Rev. Lett.* **90**(2003)241802; C. Dib, R. Rosenfeld and A. Zerwekh, hep-ph/0302068; T. Han, H. E. Logan, B. McElrath and L. T. Wang, *Phys. Lett. B***563**(2003)191; Z. Sullivan, hep-ph/0306266.
- [11] S. C. Park and Jeony-hyeon Song, hep-ph/0306112.
- [12] J. A. Aguilar-Saavegra et al. (ECFA/DFSY LC Physics Working Group Collaboration), hep-ph/0106315.
- [13] For a review, see, B. A. Kniehl, *Int. J. Mod. Phys. A* **17**(2002)1457; M. Carena and H. E. Haber, *Prog. Part.Nucl. Phys.***50**(2003)63.
- [14] V. Barger, et al., *Phys. Rev. D***49**(1994)79.
- [15] D. E. Groom et al. [Particle Data Group], *Eur. Phys. J. C***15**(2000)1; K. Hagiwora et al. [Particle Data Group ], *Phys. Rev. D***66**(2002)010001.